Lac Cardinal

Water Quality Monitoring Report

Provincial Parks Lake
Monitoring Program

Alberta
Government

Lac Cardinal Water Quality Monitoring Report - Provincial Parks Lake Monitoring Program

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Preface

Provincial Parks Lake Monitoring Program

The purpose of the Provincial Parks Lake Monitoring Program is to routinely collect information that describes the current status of water quality within a suite of recreational lakes and reservoirs (Appendix I, Table A1). These waterbodies vary considerably in terms of their physical (e.g. size, shape and mean depth), chemical (e.g. salinity, pH, alkalinity) and biological (e.g. algae and fish populations) characteristics and represent the spectrum of water quality found within other typical lakes and reservoirs in Alberta. The program, which is a collaborative effort between the departments of Environment and Tourism, Parks, Recreation and Culture, is one of the largest interdepartmental monitoring efforts in Alberta and a key component of the Provincial Lake Monitoring Network.

This report is one in a series of nineteen that provide a brief assessment of recent and historical information collected through the Provincial Parks Lake Monitoring Program in an attempt to describe current states of water quality in these recreational waters. Many questions will undoubtedly come to mind as you read this report. A detailed primer on the topic of Limnology (lake and river science) and additional resources are provided in Appendix I to aid in the interpretation and understanding of these reports.

Reports are available for the following Provincial Parks Lakes:

Beauvais Lake	Elkwater Lake	McLeod Lake	Saskatoon Lake
Cardinal Lake	Gregg Lake*	Miquelon Lake	Spruce Coulee Res.
Chain Lake	Gregoire Lake	Moonshine Lake	Steele Lake
Crimson Lake	Jarvis Lake*	Lake Newell	Sturgeon Lake
Dillberry Lake	Long Lake	Reesor Lake Res.	Winagami Lake

* Compiled in a single report.

Lac Cardinal

Lac Cardinal is a large, shallow lake located approximately 20 km west of Peace River, Alberta. The lake is part of Queen Elizabeth Provincial Park (formerly Lac Cardinal Provincial Park), and is popular for boating, sailing, and water skiing. The park was founded in 1956 and supports very diverse songbird and waterfowl populations.

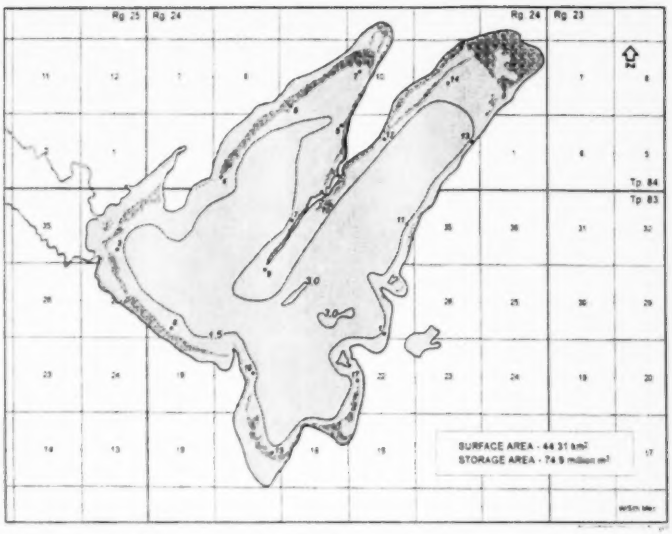


Figure 1. Bathymetry of Lac Cardinal.

Lac Cardinal is located in an area of low topographical relief comprising primarily mixed forest. There is one major surface inflow to the lake, though some additional inflow is received intermittently from Figure Eight Lake. The outflow, Cardinal Creek, flows to the Whitemud River (Figure 1).

Physical Characteristics

The area that drains into Lac Cardinal is moderately large (404 km^2; Table 1). The lake is oriented northeast-southwest and has a surface area of 52 km^2. It is very shallow for its area (maximum depth is 3.67 m) and has a water residence time of only 1.5 years (Table 1). A detailed hydrographic survey was performed in 1983, but this map is not currently available. Figure 1 presents a map that was produced in 1962, but water level was not recorded at this time. For this reason, physical characteristics presented in Table 1 are more accurate than those presented in Figure 1.

Table 1. Physical characteristics of Lac Cardinal (*at elevation 644 m).

Surface area (km^2)	52
Volume (million m^3)	83
Maximum depth (m)	3.67
Mean depth (m)	1.8
Drainage basin area (km^2)	404
Water residence time (yrs)	1.5

* Memo, J. Taggart, Hydrology Branch, Alberta Environment, 9 Sept, 1983. Data approximate.

Water Levels

Water levels have been recorded in Lac Cardinal since 1965 and data recorded since 1982 are presented in Figure 2. Average annual fluctuations are approximately 0.3 m and the total range of fluctuation is 1.6 m (high water level in 1997 compared to low water level in 1967). This is a significant amount of variation, compared to most lakes in Alberta, and has a considerable impact on shoreline characteristics because of the very low surrounding topographical relief. Corresponding with a period of low precipitation, water levels were low from summer 1999 to spring 2003 (Figure 2). Water levels have recovered with a return to higher precipitation in 2003 and 2004.

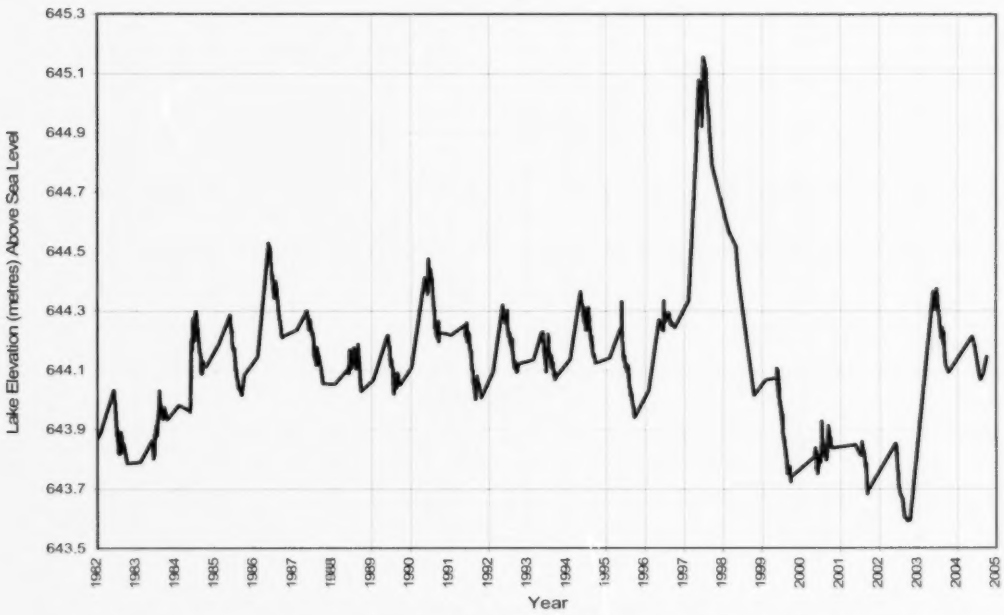


Figure 2. Historic water levels for Lac Cardinal, Queen Elizabeth Provincial Park.

Water Quality

Since 1992, water samples have been collected 2-5 times per year (except 1998, 1999, 2003 and 2004) during the open-water season (May through September). Samples were collected from the euphotic zone (i.e. from the lake's surface down to the maximum depth sunlight is able to penetrate to) at ten locations throughout the lake basin and combined to form one composite sample. Samples were typically analyzed for total phosphorus and chlorophyll-*a* concentrations and subsamples analyzed for ion concentrations, alkalinity and hardness. Secchi depth, an estimate of water clarity and algal biomass, was measured during most sampling events. On 5 occasions (winter 1994 and 2001, summer 1994, 1996 and 1997) depth profiles for both temperature and dissolved oxygen (DO) concentrations were produced by recording measurements at the surface and 1-m depth intervals to the lake bottom (See Appendix II for data).

Water Temperature and Dissolved Oxygen

Temperature and DO depth profile data indicate that Lac Cardinal is a polymictic lake, which means that it mixes completely from top to bottom often throughout the ice-free season (Figure 3; and Appendix II). This pattern is common for shallow lakes and results in uniform temperature throughout the water column (Appendix I).

The Alberta surface water quality guidelines for DO are 5.0 mg/L for instantaneous conditions, and 6.5 mg/L for longer-term conditions (calculated as a 7-day mean). For periods when early-life stages of fishes develop, the guideline is 9.5 mg/L. In the two profiles collected during winter months, concentrations of DO in Lac Cardinal were near zero, indicating that the lake probably experiences winterkills (Appendix II). Of the three summer profiles, two (August 1996, August 2001) had concentrations that met the water quality guidelines for instantaneous and longer-term conditions. The profile taken in August 1994, however, showed DO concentrations that may have resulted in summerkill. All measurements of dissolved oxygen were below 9.5 mg/L (early life stage guideline), but this is relatively common in Alberta lakes.

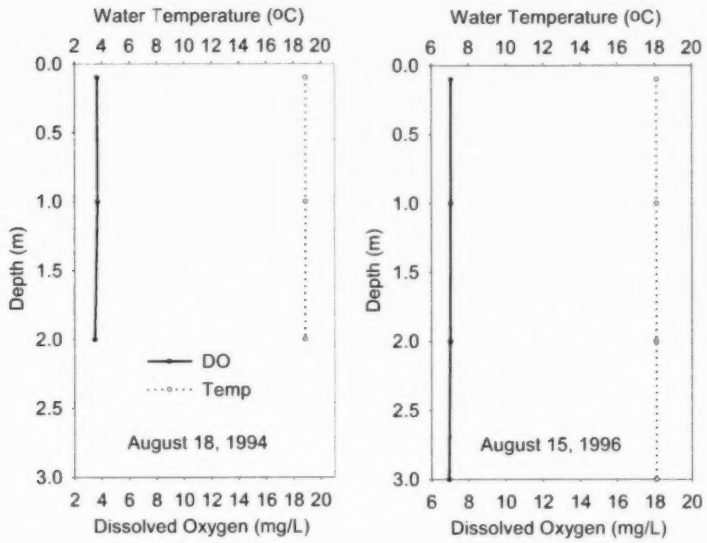


Figure 3. Temperature and DO profiles August 1994 and 1996.

Trophic State and Water Clarity

Total phosphorus (TP) and chlorophyll-*a* (Chl-*a*) concentrations are indicators of trophic state (level of fertility) in freshwater lakes and reservoirs. Phosphorus is a limiting nutrient for algal populations in most fresh waters and Chl-*a* is a direct estimate of algal biomass. Trophic state varies from oligotrophic (low TP and Chl-*a*, clear water) to hypereutrophic (very high TP and Chl-*a*, murky water). Most lakes in Alberta have naturally high nutrient and resulting Chl-*a* concentrations, but industrial, agricultural, and urban development can increase these concentrations above background levels, negatively impacting water quality (See Appendix I for more details).

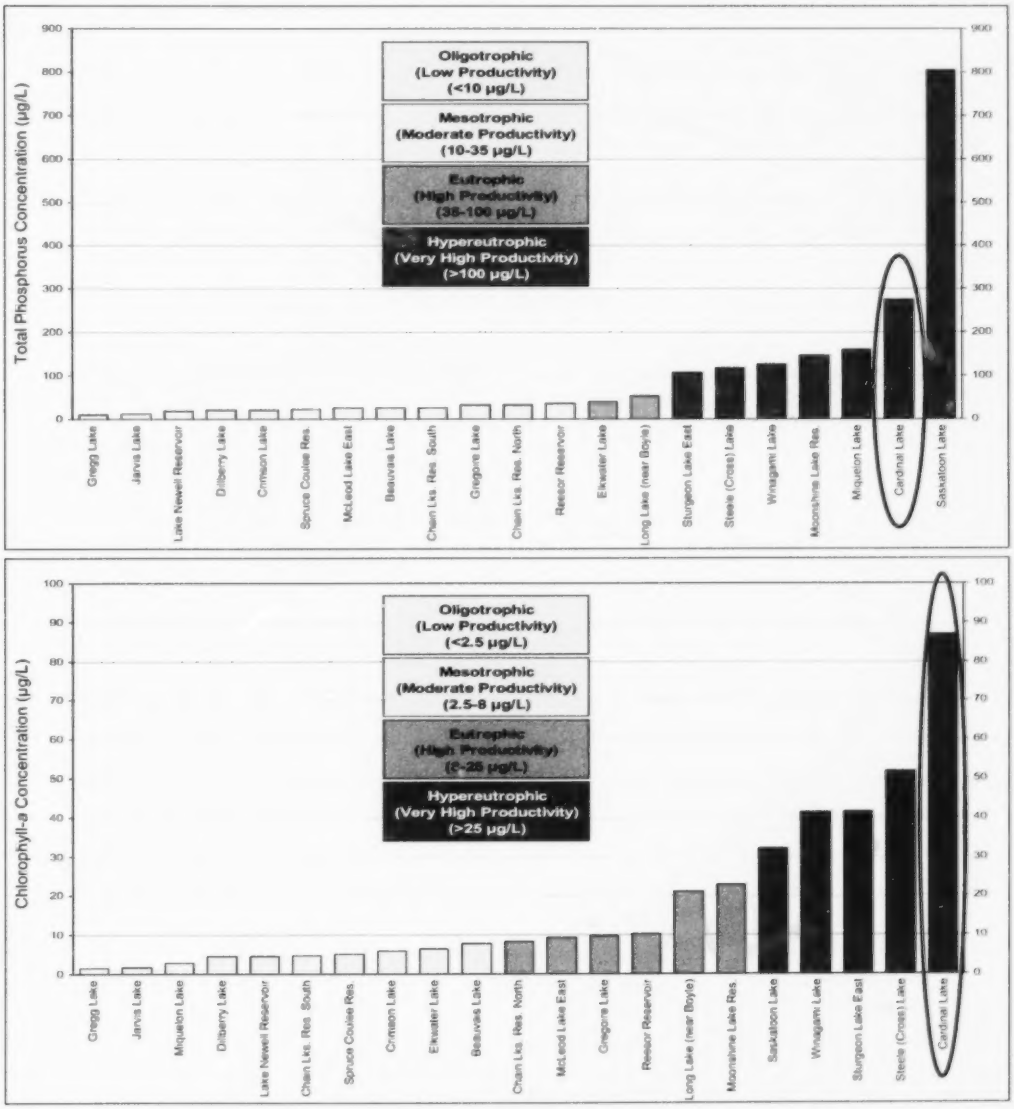


Figure 4a (top) and 4b (bottom). Trophic state of Alberta lakes in the Provincial Parks Monitoring Program based on mean total phosphorus and chlorophyll-*a* concentrations, May to October, 1982-2004.

Chl-*a* and TP data for Lac Cardinal were collected from 1992-1997 and from 2000-2002. Mean TP (280 µg/L) and Chl-*a* (87 µg/L) concentrations indicate that Lac Cardinal is hypereutrophic. Compared to other provincial park lakes, it has the highest average Chl-*a* concentration and the second-highest TP concentration (Figure 4a and b; Table 2). This results in green, turbid water in the summer that is most likely due to recycling of phosphorus from the shallow lake bottom. Lake users should exercise caution when there are cyanobacterial (blue-green algae) blooms because some common bloom-forming species produce toxins that can be harmful to humans, wildlife and domestic pets.

Seasonal patterns of Chl-*a* and TP concentrations have varied among years. In 1994, 1996, and 1997, TP peaked before Chl-*a* (July vs. August), while in 1992 and 1995 the reverse occurred. In 1993 and 2000 TP and Chl-*a* peaked at approximately the same time, although in 1993 concentrations peaked in September and in 2000 concentrations peaked in July. The lack of consistent seasonal patterns in Lac Cardinal is likely due to the shallow water depth and consequent sensitivity to climatic conditions. There do not appear to be any trends in the 9-year record of mean annual concentrations, indicating that the water quality of Lac Cardinal is relatively stable (Figure 5).

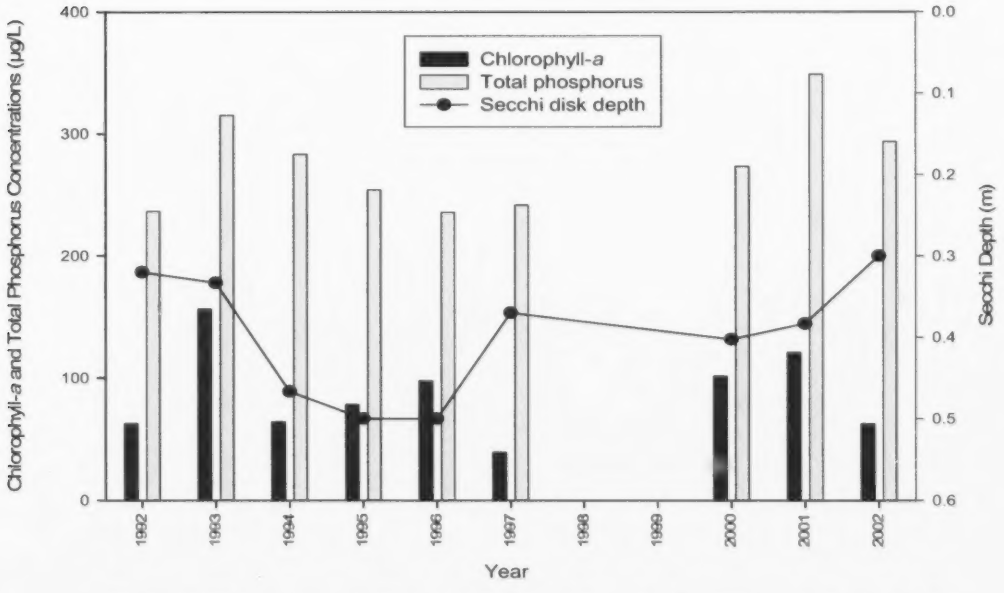


Figure 5. Mean summer (May – October) chlorophyll-*a* concentrations, total phosphorus concentrations and Secchi depth from 1992-2002.

General Water Chemistry

Lac Cardinal is a fresh, slightly alkaline (pH > 8) lake (Table 2). Alkalinity is high, so it is well-buffered against acidic deposition from snow or rainfall. It has very hard water and the dominant ions are calcium, bicarbonate, and sulfate. Inter-annual variability in

general water chemistry parameters have corresponded with changes in water level. Concentrations of major ions have generally increased with decreasing water level and vice versa. There is no evidence of long-term trends in major ion concentrations, alkalinity, or hardness in Lac Cardinal (e.g., Figure 6), suggesting that surface water and groundwater inputs have not changed substantially since 1992.

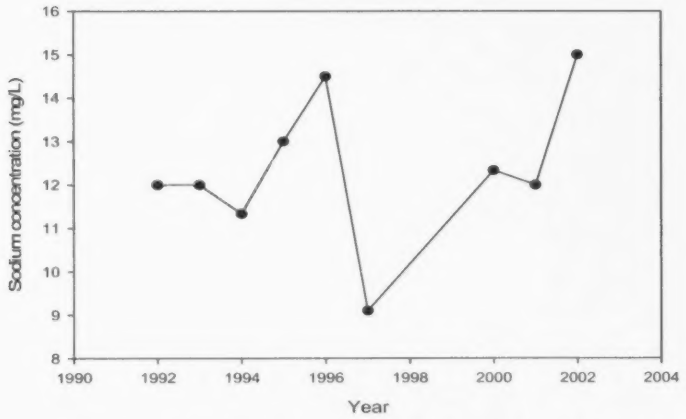


Figure 6. Sodium concentrations in Lac Cardinal from 1992-2002.

Table 2. Mean summer values for water quality variables in Lac Cardinal from 1992-2002.

Parameter	Mean	Maximum	Minimum	Standard Deviation
Alkalinity as $CaCO_3$ (mg/L)	122	134	78	18.04
Bicarbonate (mg/L)	145	164	90	23.40
Calcium (mg/L)	56.1	67.3	36.9	9.69
Carbonate (mg/L)	4.75	14.0	1.48	4.45
Chloride (mg/L)	4.02	16.13	1.90	4.60
Chlorophyll-*a* (µg/L)	87.0	156.3	39.2	35.99
Fluoride (mg/L)	0.26	0.30	0.24	0.02
Hardness (mg/L)	235	277	178	29.92
Iron (mg/L)	0.17	0.19	0.13	0.03
Magnesium (mg/L)	23.2	26.7	17.5	2.78
pH	8.22	8.60	7.83	0.26
Total Phosphorus (µg/L)	280	350	240	40
Potassium (mg/L)	18.2	23.0	14.2	2.37
Secchi depth (m)	0.40	0.50	0.30	0.08
Silica (mg/L)	3.79	9.90	0.29	3.47
Sodium (mg/L)	12.4	15.0	9.10	1.73
Specific Conductivity (µS/cm)	525	596	453	46.59
Sulfate (mg/L)	145	167	96.9	22.87
Total Dissolved Solids (mg/L)	334	380	276	35.99

Summary

Lac Cardinal is a large, shallow, hypereutrophic lake. Due to its high productivity, there are often cyanobacterial blooms and low DO concentrations associated with bloom decomposition. Water quality remained relatively stable from 1992-2002.

References

Mitchell, P.A. 1997. Lac Cardinal– Assessment of Water Quality 1992-1996. Alberta Environmental Protection, Natural Resources Service. Memorandum. File No. GEN., 96-064.

Appendix I

The purpose of the **Provincial Parks Lake Monitoring Program** is to routinely collect information that describes the current status of water quality within a suite of recreational lakes and reservoirs (Figure A1, Table A1). Though not exhaustive, the parameters measured in this program are well-established indicators of water quality. Most of these are influenced by both natural (i.e. climate, geology and landscape morphology) and anthropogenic (i.e. agriculture, urbanization and recreational activities) perturbations in the lake basin and surrounding catchment. For example, phosphorus is a key nutrient for growth of algae and aquatic plants and thus an important determinant of lake productivity. Many lakes in Alberta naturally contain moderate concentrations of phosphorus as a result of nutrient-rich soils within their watersheds. Lakes with large catchment areas in relation to their surface areas (i.e. high catchment area:lake surface area ratio) often contain even greater concentrations of naturally derived phosphorus, as they receive proportionately more particulate and dissolved substances (e.g. salts, nutrients, etc.). However, natural levels of phosphorus in a lake can be elevated by land use changes such as increased crop production, livestock grazing or urban development (Figure A3). Elevated phosphorus concentrations can cause increases in the frequency and magnitude of cyanobacterial blooms resulting in noxious odors, potent toxins, low dissolved oxygen concentrations and degraded fish habitat. Large increases in nutrients may also indicate sewage inputs, which may raise human health concerns such as the presence of harmful bacteria (e.g. toxic *E. coli* strain O157:H7) or protozoans (e.g. *Cryptosporidium*).

This appendix provides an introduction to lake science and an explanation of lake/reservoir water quality descriptors used in the preceding report.

Further information is available at:

Alberta Environment - Surface Water Quality Home Page
http://www3.gov.ab.ca/env/water/SWQ/index.cfm

Atlas of Alberta Lakes
http://sunsite.ualberta.ca/Projects/Alberta-Lakes/

For access to detailed provincial water quality information including On-line Surface Water Quality Reports and Data, Water Advisories and Warnings, and Water Supply Out'look, please see:

Alberta Environment - Water Information Centre
www3.gov.ab.ca/env/water/water_information_centre.cfm

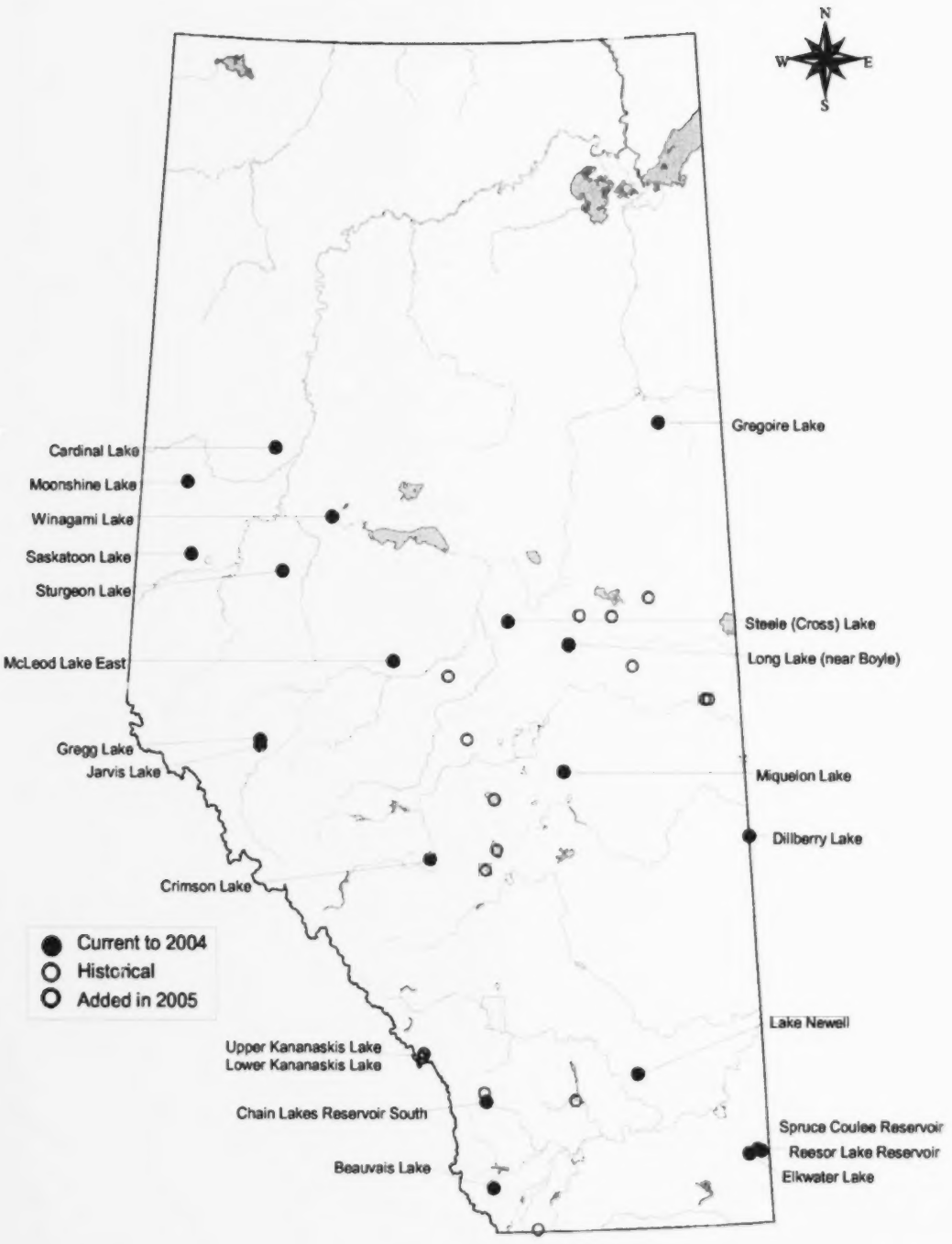


Figure A1. Map showing lakes and reservoirs sampled as part of the Provincial Parks Lake Monitoring Program. Sampling has ceased at historical locations (red circles) and continues at current locations (blue dots). Upper and Lower Kananaskis Lakes (black circles) are historical sites that were reintroduced to the program in 2005.

Table A1. List of lakes and reservoirs included in the Provincial Parks Lake Monitoring Program. Some corresponding physical, chemical and biological characteristics are also listed.

Lake/Reservoir	Surface Area (Km^2)	Catchment Area (Km^2)	Mean Depth (m)	Specific Cond. ($\mu S/cm$)	Alkalinity (mg/L as $CaCO_3$)	pH	[TP] ((g/L)	[Chl-a] ((g/L)
Beauvais Lake	0.89	7.09	4.3	299	157	8.33	25.58	7.80
Cardinal Lake	52	404	1.8	525	122	8.22	280	87.02
Chain Lake (south)	3.12	209	5.4	302	151	8.33	26.10	4.73
Chain Lake (north)				328	163	8.37	33.01	8.41
Crimson Lake	2.32	1.75	2.2	260	141	8.55	20.78	5.86
Dillberry Lake	0.80	11.8	2.8	382	205	8.61	20.26	4.46
Elkwater Lake	2.31	25.7	3.5	477	216	8.50	39.71	6.37
Gregg Lake	1.34	162.9	18	344	184	8.23	10.31	1.59
Gregoire Lake	25.8	232	3.9	133	57	7.61	32.16	9.73
Jarvis Lake	1.45	70.2	25	344	184	8.23	10.31	1.59
Long Lake (by Boyle)	5.84	82.4	4.3	387	194	8.40	51.56	20.79
McLeod Lake (east)	3.73	45.9	5.1	298	146	8.22	25.33	9.33
Miquelon Lake	8.72	35.4	2.7	8088	1485	9.41	159	2.91
Moonshine Lake	0.28	6.84	1.3	705	157	8.13	146	22.67
Lake Newell	66.4	84.6	4.8	350	126	8.24	17.89	4.49
Reesor Lake Res.	0.51	5.58	3.7	235	124	8.29	34.86	10.26
Saskatoon Lake	7.47	31.8	2.6	1068	577	8.93	805	31.96
Spruce Coulee Res.	0.21	4.09	3.3	232	122	8.19	22.86	5.16
Steele Lake	6.61	255	3.2	291	155	8.28	117.33	51.80
Sturgeon Lake (east)	49.1	571	5.4	184	77	7.82	106.61	41.52
Winagami Lake	46.7	221	1.7	480	179	8.37	126.21	41.30

* Kananaskis Lakes were added to the program in 2005, reports not available at this time. [TP] = total phosphorus concentration, [Chl-*a*] = chlorophyll-*a* concentration.

Water Temperature

Temperature affects many aspects of surface water quality. Water temperature is a very important factor regulating biological, physical, and chemical processes. Temperature influences the solubility, and thus availability, of various chemical constituents in water. Most importantly, temperature affects dissolved oxygen concentrations in water (oxygen solubility decreases with increasing water temperature). Temperature also regulates metabolic, growth and reproductive rates of living organisms including bacteria, algae, invertebrates and fishes. Hence, temperature is paramount in determining which fish species can survive and inhabit a given water body. Water temperature is usually measured from surface to bottom in a series of depth intervals; this results in temperature-depth "profiles" (Appendix II).

Air temperatures, groundwater inputs, wind, lake depth, and a number of other variables affect water temperature in a lake or reservoir. In Alberta, season is also an important factor regulating water temperature. These factors also influence how uniform water temperature will be with depth. Uniform temperature from the surface to the bottom

means that a lake can circulate or mix completely, thus distributing dissolved substances such as nutrients and oxygen equally throughout the water column. Non-uniform temperature resulting from heating or cooling (usually at the surface) causes a temperature-dependent density gradient to form through the water column – a process known as **thermal stratification** (Figure A2).

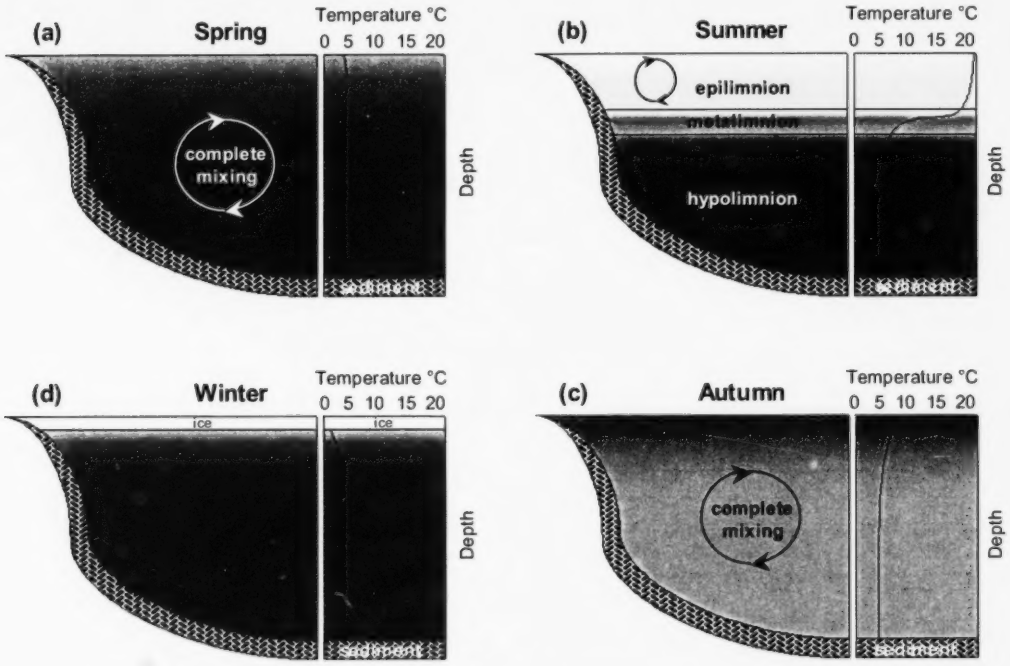


Figure A2. Depiction of annual lake mixing and thermal stratification within Alberta's lakes and reservoirs.

Nearly all of Alberta's lakes/reservoirs are covered in ice during winter months (Figure A2 *d*). During this period, water near lake bottom is usually about 4°C – the temperature at which water has greatest density. Immediately under the ice, water temperature can be 0°C. For a brief period in spring when the ice disappears, the water temperature becomes uniform throughout and wind induced circulation causes the lake to mix completely – an event known as the spring turn-over. As spring progresses, surface waters warm and become less dense than underlying cooler waters (Figure A2 *a*). Continued warming and wind action allow warmer water to mix downwards through the water column. In deeper lakes, a point will eventually be reached when wind action alone cannot generate sufficient current to overcome the differences in density of the cool (more dense) underlying waters with that of the warm (less dense) surface waters. Thermal layers result. The uppermost, warm, well-mixed layer is called the **epilimnion** and the cool (often 4°C), dense bottom layer is called the hypolimnion (Figure A2 *b*). Separating these two is a distinct middle layer of water characterized by steep gradient in both temperature and density called the **metalimnion**. The depth-plane of maximum temperature change is

referred to as the **thermocline**. It should be noted that the thermocline is not static and can move vertically depending on the strength of wind-induced currents.

As summer progresses into fall, decreasing air temperatures cause surface waters to cool. As this cool dense water sinks, wind-induced circulation causes the epilimnion to expand downward penetrating the metalimnion. With continued cooling, the thermocline is pushed deeper. Eventually, the metalimnion disappears, the thermocline is overcome, and the water column reaches a uniform temperature and density allowing mixing of the water column – an event known as the fall turn-over (Figure A2 *c*). Lakes that experience both spring and fall turnover, are termed **dimictic** lakes (i.e. two periods of mixing or mixis). However, not all lakes follow this pattern and there are other patterns of thermal stratification in Alberta lakes. Cold **monomictic** lakes (only one turn-over), for instance, are stratified in winter but remain mixed throughout the open-water season. **Polymictic** lakes mix frequently and stratification events are rare and short. Most shallow lakes (those < 15 m deep) in Alberta are polymictic. Lastly, in rare instances extremely deep lakes never mix completely and remain stratified permanently – these are called **meromictic** lakes and are very rare in Alberta.

Dissolved Oxygen

Aquatic organisms such as fish and invertebrates require dissolved oxygen in certain concentrations in order to live. In general, dissolved oxygen concentrations are higher in oligotrophic, deep, cool lakes and lower in eutrophic, shallow, warm lakes. Oxygen is added to water by photosynthetic activity of plants, algae and cyanobacteria, gas exchange with the atmosphere, and groundwater inputs. It is removed by respiration of bacteria, plants (algae and cyanobacteria), and animals, as well as various chemical processes. In winter, dissolved oxygen concentrations are often low because ice cover restricts oxygen entering from the atmosphere and photosynthesis is greatly reduced (overlying snow cover restricts sunlight from penetrating through ice). If concentrations of dissolved oxygen become low enough, winterkill can occur, where the less tolerant organisms, particularly some sportfish species, die. Winterkill occurs primarily in very shallow, productive lakes in Alberta.

In summer, dissolved oxygen concentrations can become very low in the hypolimnion of stratified lakes because there is no photosynthesis (no light in the deep part of the lake), but respiration is often high. If a lake is eutrophic or hypereutrophic, collapse and degradation of algal blooms can result in low dissolved oxygen concentrations and, occasionally, summer kill. The Canadian Council of Ministers of the Environment guideline for the protection of aquatic life (PAL) is 6.5 mg dissolved oxygen per liter of water.

Nutrients - Nitrogen

Nitrogen is an essential nutrient for the growth of plants, algae and cyanobacteria. Nitrogen is highly dynamic in the environment and may be transformed into various inorganic forms and incorporated in organic molecules (proteins and nucleotides). Inorganic forms of nitrogen include dissolved elemental nitrogen (N_2), nitrate (NO_3^-),

nitrite (NO_2^-) and ionized ammonia or ammonium (NH_4^+). Ammonia (NH_3) also occurs, but is unstable below pH 9 and rapidly ionizes into NH_4^+. The most abundant form of nitrogen on a global scale is atmospheric N_2, which comprises 78% of the atmosphere. Atmospheric N_2 enters surface water at the air/water interface. During turbulent periods (e.g. wind-induced mixing), the N_2 content of surface water is usually in equilibrium with atmospheric N_2, but dissolved concentrations may decline in the epilimnion of stratified lakes due to reduced solubility. Though N_2 is abundant, most primary producers cannot assimilate this form of nitrogen directly. In order for it to be of use to these organisms, it must first be "fixed" (combined with H+) into bioavailable forms such as NH_3 or NH_4^+. In most lakes, heterocystous cyanobacteria are primarily responsible for the fixation of N_2. Heterocysts are specialized cells modified for fixing atmospheric nitrogen. Ammonia (including un-ionized NH_3 and ionized NH_4^+) is an important form of nitrogen in most terrestrial and aquatic ecosystems. Ammonia is the first form of nitrogen released when organic matter decays and is readily used by most plants. Under oxygenated conditions, ammonia is rapidly oxidized to NO_2^- and then to NO_3^- by bacteria.

In areas of intense agriculture, NO_3^- can accumulate in the soil when nitrate salt, ammonia or organic (treated sewage and manure) fertilizers are applied. Nitrate is the most highly oxidized and, consequently, the most soluble form of nitrogen. Due to its solubility, NO_3^- binds weakly to soil particles and has a high potential to migrate (leach) down through the soil profile to groundwater. Nitrogen enriched (contaminated) groundwater and agricultural runoffs are primary sources of NO_3^- and organic nitrogen to surface water. Other significant sources of NO_3^- to both surface- and groundwaters include urban fertilizer use (e.g. fertilization of residential and recreational or golf course turf grass), domestic wastewater treatment effluents, industrial discharge, leachates from landfills and atmospheric washout of airborne pollutants. Surface waters lying within natural or undisturbed watersheds usually contain only minute amounts of NO_3^- (and NO_2^-) compared to those in developed watersheds. Once in surface water, NO_3^- (and NO_2^-) does not evaporate and is likely to remain in water until consumed by plants or other organisms. As a result, nitrogen enrichment often contributes to increased growth of aquatic plants and algae, resulting in eutrophication (see *Eutrophication* below).

Some forms of nitrogen can be highly toxic to humans and other animals. High levels of NO_3^- in drinking water can be harmful to humans and livestock as it is converted into NO_2^- within the intestinal tract. Nitrites are highly toxic since they affect the ability of red blood cells to carry oxygen – a condition known as methemoglobinaemia. High concentrations of NH_4OH can affect hatching and growth rates of fish and cause developmental abnormalities in gill, liver, and kidney tissues. Currently there is no Alberta water quality guideline for the PAL established for NO_3^-. The guideline for NO_2^- is 0.06 mg/L. The Alberta water quality guideline for PAL is 1.37 mg/L of ammonia at pH 8 and 10°C to 2.20 mg/L at pH 6.5 and 10°C.

The various forms of nitrogen are typically quantified as: (1) total kjeldahl nitrogen (TKN) – the total concentration of nitrogen present as ammonia or bound in organic compounds; (2) total inorganic nitrogen (TIN) – the total combined NO_3^-, NO_2^- and ammonia ($NH_3 + NH_4^+$) concentrations; and (3) combined $NO_3^- + NO_2^-$ concentrations.

Nutrients - Phosphorus

Phosphorus is an essential element required by all organisms for the basic processes of life. Phosphorus plays a key role in the storage and transfer of energy within the cells of plants and animals and is a component of nucleic acids (DNA and RNA). In the environment, phosphorus usually exists in an oxidized state as the negatively charged phosphate ion, called orthophosphate (PO_4^{-3}). Soluble (dissolved) orthophosphate is also referred to as soluble reactive phosphorus as it can: (1) readily react with positively charged iron, aluminum, and calcium ions to form relatively insoluble compounds, or (2) easily be taken up by plants and animals and incorporated into tissues as organically bound phosphates.

The amount of phosphorus in surface water is influenced to a large degree by the composition of underlying bedrock, surficial deposits and soils within a watershed. Not surprisingly, the watershed is the largest natural source of phosphorus transported to most lakes (Figure A3). Surface runoff from spring snowmelt and summer rainstorms transports phosphorus-rich minerals, soil particles and organic matter directly to lake basins or to the rivers and streams entering them. Lakes with large watersheds relative to lake surface area typically contain more phosphorus (and nitrogen) than those with smaller watersheds. Phosphorus entering lakes with surface inflow also includes that which is produced in and exported from lakes further upstream. Consequently, headwater lakes generally contain fewer nutrients than those further downstream. **Due to the phosphorus-rich sedimentary bedrock and derived soils that exist throughout much of Alberta, lakes within the province tend to contain naturally elevated concentrations of phosphorus.** Atmospheric deposition of phosphorus via rain, snow and airborne particles (dust) to the surface of a lake represents a minor natural source of phosphorus for most lakes. However, for lakes with small watersheds relative to lake surface area, atmospheric deposition may constitute a greater proportion of the total external phosphorus load compared to lakes of similar area with larger drainage basins. Groundwater may also be a source of nutrients (e.g. nitrates) to lake basins. Because orthophosphate is so highly reactive, either becoming adsorbed to soil particles or incorporated into inorganic and organic compounds, its movement into groundwater is usually limited.

Compared to other nutrients, such as carbon and nitrogen, phosphorus occurs in least abundance relative to the needs of plants, algae and cyanobacteria. Hence, phosphorus, as soluble orthophosphate, is often the growth-limiting nutrient in most north-temperate freshwater lakes. When added to surface water, phosphorus stimulates the growth of aquatic plants, algae and cyanobacteria. This organically bound phosphorus is eventually released following microbial decomposition and mineralization on the lake's bottom sediments. If oxygen is present near the bottom, orthophosphate will quickly bind to soluble iron oxides and co-precipitate to the sediment. In this regard, sediments are sinks (storage sites) for phosphorus. If, however, oxygen becomes depleted (due to excessive decomposition etc.) iron oxides and orthophosphates dissociate in soluble form and migrate from the sediment into the overlying waters.

In most of Alberta's lakes, prolonged decomposition of plants and algae occurs during the winter months when lakes tend to be ice covered. Oxygen is gradually consumed through the winter months, producing anoxic conditions conducive to the release of sediment-bound phosphorus to the water column. Following the melt of ice in the spring, phosphorus circulates throughout the water column and becomes readily available for the annual growth of aquatic plants and algae. This process of phosphorus release from the sediments to the water column is called internal loading, and can contribute significant amounts of the nutrient annually. Internal loading also occurs during the open water months in stratified lakes (i.e. deep water isolated from well-circulated upper water by a distinct difference in water temperature and accompanying density gradient) following the rapid decomposition of severe growths of algae and cyanobacteria. As a result, the hypolimnion becomes depleted in oxygen. Under anoxic conditions, bottom sediments release phosphorus into the water column. When subsequent wind action overcomes the temperature related density gradient, stratification is disrupted, and the newly dissolved nutrients circulate up into the shallow, illuminated surface waters where plants and algae actively grow.

Total phosphorus (TP) is a measure of all phosphorus fractions in water, including inorganic and organic particulate and dissolved forms. In phosphorus-limited lakes, TP is an important determinant of the potential for primary biological production. Consequently, it can be directly related to the biomass of phytoplankton (i.e. suspended algae and cyanobacteria, typically estimated by chlorophyll-*a* concentration) and indirectly related to water clarity or transparency, as estimated by Secchi depth (see *Water Clarity* below). In the past, the concentration of TP has been used to define the trophic state of lakes – a biological condition that refers to the degree of organic (biomass) production (see *Trophic State* below). It should be recognized however, that the degree of biological production, and hence trophic state, is merely influenced by phosphorus (and not defined by it) and that many additional determining factors,

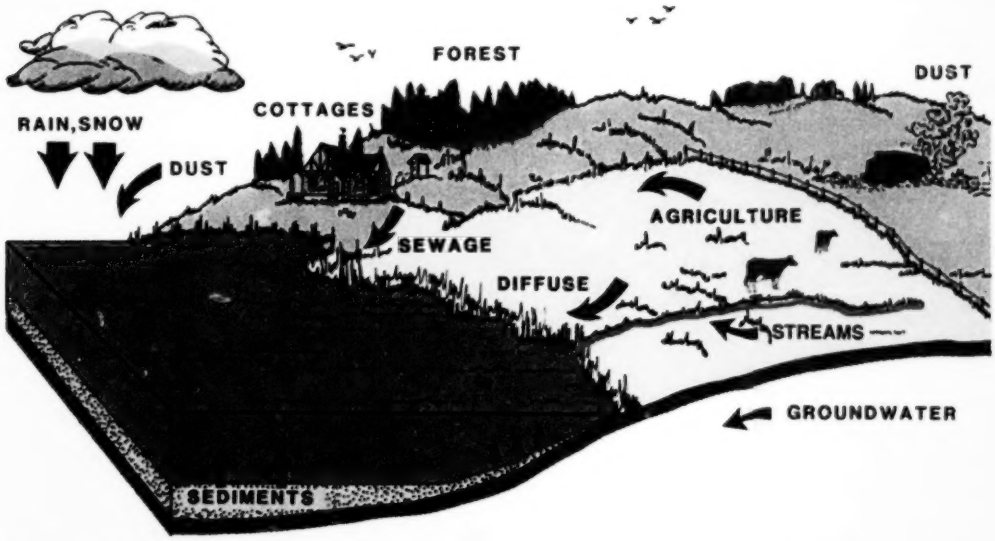


Figure A3. Sources of nutrients to lakes and reservoirs, including atmospheric deposition, surface runoff, agricultural and residential inputs, groundwater and internal sediment loading.

including salinity, pH, turbidity, etc. must also be considered. Regardless, TP concentration continues to be used solely, or in combination with chlorophyll-*a* concentration and Secchi depth in indices as a means of classifying lake and reservoir water quality based on trophic state or degree of eutrophication. Phosphates are not toxic to people or animal, though digestive problems can occur as a result of exposure to extremely high levels. The Alberta water quality guideline for Protection of Aquatic Life is 0.05 mg/L of total phosphorus.

Chlorophyll-a

Algal (and cyanobacterial) biomass can be used as a measure of photosynthetic production in a lake or reservoir. One method of determining biomass is to measure total biovolume – the total volume of algae and cyanobacteria per volume of water. Unfortunately, measuring biovolume accurately involves time-consuming microscopic enumeration and requires appreciable expertise. A commonly used surrogate is the concentration of chlorophyll-*a* (Chl-*a*), which is a photosynthetic pigment present in plants, algae and cyanobacteria. Since Chl-*a* is integral to photosynthesis, it serves as the link between primary productivity (rate of carbon incorporation by plants, algae and cyanobacteria) and production (biomass). Since, Chl-*a* acts as an empirical link between nutrient (phosphorus) concentration and algal production and because it is easy and relatively inexpensive to measure, it has found widespread use as the principal indicator of lake trophic state (see *Trophic State* below).

It should be noted that the use of Chl-*a* is not without its drawbacks, since the amount of Chl-*a* in an algal cell may vary considerably depending on the species and physiological condition of the cell. Algae and cyanobacteria subject to low light conditions may contain more Chl-*a* than those exposed to high light intensity. Similarly, young, actively growing and reproducing cells may contain greater amounts of Chl-*a* compared to senescent cells. Despite this variability however, relationships between Chl-*a*, algal biovolume and density, which suggest Chl-*a* concentrations change as population density change, have long been recognized.

Water Clarity (Transparency)

Most lake users prefer clear (highly transparent) lake water for recreational purposes. The clarity or transparency of surface water relates to the proportion of light that passes through water without attenuation or absorption. The further light penetrates through a column of water, the more transparent or 'clear' it is said to be. Both suspended particles and dissolved material within the water column influence transparency. These include living and dead organisms and their byproducts (e.g. phytoplankton, zooplankton etc.), inorganic particulates (e.g. eroded minerals, soils and sediments), and colored dissolved organic compounds (e.g. plant derived humic substances). As the number of particles or the concentration of colored dissolved compounds increase, so does attenuation (absorption and scattering) of light entering the water.

Transparency of surface waters can be determined with electronic devices that directly measure the amount of light occurring with depth. These devices are not only expensive,

but require some degree of experience, as well as routine maintenance and calibration. A more widely used instrument for measurement of lake/reservoir water transparency is the Secchi disk – a relatively inexpensive black and white plate about 25.4-30.5 cm (10-12 inches) in diameter that is lowered through the water column. The Secchi depth is the greatest depth at which the disk can be visually detected and is most accurately determined by lowering the disk until it cannot be seen, then raising it to the point it reappears. The mid-point between the depth where it disappeared and then reappeared is the Secchi depth.

The dominant factor affecting water transparency can depend on variables such as season, climate, lake morphology, etc. For instance, temporary reductions in water transparency can result from an influx of both inorganic particulates and dissolved humic compounds during spring thaw and large storm events. Wind-induced mixing may cause sediments in shallow lakes (i.e. < 5 m maximum depth) to re-suspend periodically throughout the open water season. In this case, the suspended sediments are primarily responsible for increasing turbidity and reducing clarity. As concentrations of inorganic particulates and dissolved humic compounds increase, Secchi depth decreases. For many nutrient-rich north-temperate lakes, such as those in Alberta, transparency is largely influenced by phytoplankton density during the open water season. In lakes of sufficient depth (low risk of sediment re-suspension) and low humic concentration (low color), Secchi depth can be highly correlated with algal biomass (as measured by Chl-*a* concentration). Consequently, Secchi depth is not only used as a surrogate for algal biomass but is widely used as an inexpensive estimator of trophic state.

Trophic State

Trophic state refers to the overall level of biological productivity (or fertility) of a lake and is usually defined by concentrations of key nutrients (primarily phosphorus) and algae that are present (Table A2). Lakes can be categorized into one four trophic states:

- **Oligotrophic** (low productivity)
- **Mesotrophic** (moderate productivity)
- **Eutrophic** (high productivity)
- **Hypereutrophic** (very high productivity)

Lakes with high trophic states (eutrophic and hypereutrophic) often have murky, green water, low biodiversity, and a high number of coarse fish (e.g. white sucker) relative to sport fish. While many of Alberta lakes are naturally eutrophic or hypereutrophic, other lakes have elevated trophic states because of human activities in the watershed (see *Eutrophication* below).

Table A2. Indicators of trophic state.

Trophic Status	Total Phosphorus (µg/L)	Total Nitrogen (µg/L)	Chlorophyll-*a* (µg/L)	Secchi depth (m)
Oligotrophic	<10	<350	<2.5	>4
Mesotrophic	10-35	350-650	2.5-8	4-2
Eutrophic	35-100	650-1200	8-25	2-1
Hypereutrophic	>100	>1200	>25	<1

Eutrophication

Eutrophication refers to the accumulation of nutrients and progressive increases in organic productivity within aquatic ecosystems. Eutrophication can occur naturally, such that nutrient-poor, unproductive (oligotrophic) lakes gradually become nutrient-enriched, productive (eutrophic) waters over time. The increase in primary production (plant, algal and cyanobacterial growth), indicative of a shift from an oligotrophic to eutrophic state, leads to various changes in water quality, including a reduction in water clarity and dissolved oxygen levels. Natural eutrophication can occur over relatively long periods of time and is dependent on factors such as geology and climate. In contrast, cultural or anthropogenic eutrophication significantly magnifies natural processes and results from activities that greatly accelerate nutrient loading to surface waters. Urbanization (elevated runoff due to land clearing/pavement and direct sewage disposal), agricultural development (tillage, animal waste and fertilizer use) and industrialization (deforestation and waste/byproduct disposal) are human activities that cause phosphorus (and nitrogen) enrichment. In the past, phosphates were key constituents of many commercial cleaning solutions and household detergents. The extensive application of these phosphate-containing products led to widespread eutrophication of surface waters until efforts were made by governments, detergent manufacturers and consumers to reduce their use. Organic phosphates in sewage are mineralized to orthophosphate by microbes in wastewater treatment processes or by bacteria in receiving waters and continue to be a major source of phosphorus. As well, excessive and improper application of phosphorus fertilizers (typically as calcium phosphate rock, ammonium phosphate or manure) and other chemicals, such as phosphate-based organic pesticides (organophosphates), results in significant loading of phosphorus to surface waters.

General Water Chemistry

Lake water contains dissolved and suspended materials that have been transported into the system via snowmelt, rain, groundwater, or inflow streams. There are many minerals in lake water and, when dissolved, these form electrically charged ions. Common ions include bicarbonate, carbonate, sodium, chloride, calcium, magnesium, potassium, and sulfate. Relative concentrations of these ions help determine, among other things, specific conductivity, alkalinity and water hardness. Below are definitions and descriptions for a number of general water chemistry variables that are analyzed on a routine basis as part of the Provincial Park Lakes Monitoring Program.

pH: is a measure of the concentration of hydrogen ions [H^+] on a negative logarithmic scale (i.e. pH = -log [H^+]) ranging from 1 (high [H^+] or strongly acidic) to 14 (low [H^+] or strongly basic). Thus, pH changes 1 unit for every power-of-ten change in [H^+] and represents a tenfold (10^1) difference in acidity. Pure water, which has a pH of 7 (i.e. pH = -log [1.0×10^{-7}] = 7.00), is regarded as neutral. Water with a pH of less than 7 is considered acidic and that with pH greater than 7, basic or alkaline. Watershed geology is a major factor affecting the natural pH of surface waters. Alkaline and acidic compounds are derived from the weathering of bedrock, surficial deposits and soil within a drainage basin. Calcite-rich ($CaCO_3$) sedimentary bedrock and surficial deposits, including limestones, dolomites and calcite-cemented sandstones, dissolve relatively easy and contribute carbonate (CO_3^{-2}) and bicarbonate (HCO_3^-) to surface water. Carbonates bind to and neutralize H^+, effectively increasing alkalinity and pH. Most lakes and reservoirs in Alberta are situated in watersheds dominated by carbonate-rich glacial deposits and soils. As a result, most tend to be alkaline and have pH levels between 7 and 10. In contrast, lakes situated in carbonate-poor, hard rock basins of igneous origin (e.g. granite), such as those located on the Canadian Shield near the northeastern boundary of Alberta, contain little carbonate, have poor buffering capacity and tend to have pH levels slightly below 7. Runoff from forests and marshes is often slightly acidic due to the presence of organic (humic) acids produced by decaying vegetation. Lakes receiving runoff that is rich in naturally derived organic matter or anthropogenically-derived organic pollution (e.g. ferrous sulphate and sulphuric acid from acid mine drainage; nitrogen oxides and sulphur dioxides from acid deposition) tend to be acidic. For instance, brown water lakes in northern Alberta that receive humic acid-enriched runoff from bogs have pH levels below 7 and as low as 5.

Water quality is greatly affected by pH. Of greatest concern is the influence of pH on the chemical speciation of common metals. Metal cations compete with H^+ for binding sites on available anions (e.g. hydroxide, sulphate and phosphate) to form insoluble compounds that precipitate to the sediments. With decreasing pH, metal cations become increasingly out-competed by H^+ and consequently liberated to overlying water. The mobilized (solubilized) forms of many metals are available for uptake by and can cause extreme physiological damage to aquatic organisms. For example, aluminum, the most abundant metal in the earth's crust, enters surface waters naturally with the weathering of aluminum-containing rocks and minerals and as an anthropogenic constituent of mining wastes, coal combustion (atmospheric deposition) and industrial and municipal discharges. At the pH of most surface waters (pH 6 to 9), aluminum is only sparingly

soluble and precipitates to the sediment predominantly as aluminum hydroxide, $Al(OH)_3$. With decreasing pH (between 5 and 6), aluminum forms hydroxyaluminum ions, including $Al(OH)_2^+$ and $Al(OH)^{2+}$. As pH continues to decrease below 5, the hydrated trivalent ion, $Al(H_2O)_6^{3+}$, a highly soluble and toxic form of aluminum, becomes increasingly prevalent. Most forms of aquatic life tend to be very sensitive to pH and are intolerant of pH below 5.7. Few organisms can survive below a pH of 4. High pH is also of concern as the concentration of ammonium hydroxide increases above pH 9. Most aquatic organisms are intolerant of environments with pH greater than 9. Cyanobacteria are a notable exception. They not only prefer higher pH conditions (up to about 10), but also are capable of increasing pH through excessive photosynthesis. This is usually detrimental to the growth of other algae. In Alberta, the guidelines for the protection of aquatic life require that pH be in the range of 6.5 to 8.5, but not altered by more than 0.5 pH units from background values. The CCME guideline for the protection of aquatic life is 6.5 to 9.0.

Alkalinity: is a measure of the capacity of water to neutralize acid (i.e. a measure of the buffering capacity of water). Alkalinity of natural waters is due to the presence of bases – primarily bicarbonate (HCO_3^-) and carbonate (CO_3^{-2}) – and is expressed in units of milligrams per liter (mg/L) of calcium carbonate ($CaCO_3$). It does not refer to pH, but instead refers to the ability of water to resist change in pH. Waters with low alkalinity are very susceptible to changes in pH, while those with high alkalinity are able to neutralize acid, thus maintaining stable pH. The alkalinity of surface waters is determined to a large extent by the composition of the underlying bedrock, surficial deposits and soils within a watershed. Surficial deposits and soils derived primarily from calcite-rich ($CaCO_3$) sedimentary bedrock, such as limestone and dolomite, dissolve relatively easily to yield CO_3^{-2} and HCO_3^-. Lakes located in catchments of these types generally contain large concentrations of CO_3^{-2} and HCO_3^- (i.e. > 100 mg/L $CaCO_3$). These alkaline lakes are well buffered. In addition, (bi)carbonates reduce levels of dissolved metals in water (e.g. lead, arsenic and cadmium) by forming compounds that precipitate the metals out of solution. In contrast, lakes located in watersheds dominated by igneous rock (e.g. granite) and carbonate-poor soil typically contain low concentrations of CO_3^{-2} and HCO_3^- (i.e. < 20 mg/L $CaCO_3$). Lakes with alkalinity levels below 10 mg/L are poorly buffered and very susceptible to changes in pH. Due to the preponderance of carbonate-rich glacial deposits and soils within provincial watersheds, most freshwater lakes in Alberta contain high levels of CO_3^{-2} and HCO_3^- and, thus, are characterized by high alkalinity (> 100 mg/L $CaCO_3$). The alkalinity of the province's saline lakes can greatly exceed that of its freshwater lakes. For example, the alkalinity of saline Oliva Lake has been recorded as high as 25,000 mg/L $CaCO_3$, whereas lakes situated within the carbonate-poor, granite-dominated basins of the Canadian Shield located in the extreme northeastern portion of Alberta generally have alkalinities of less than 15 mg/L $CaCO_3$. Brown water lakes of northern Alberta are perhaps the most susceptible to acid deposition since alkalinity can be below 5 mg/L $CaCO_3$. Wastewater treatment plant effluents rich in carbonate and bicarbonate from household cleaning agents and food residues can contribute to the alkalinity of surface waters. Similarly, industrial effluents can contain high concentrations of carbonates and other bases, including borates, silicates, phosphates, ammonium and sulphides.

Although high alkalinity may appear beneficial within a lake (i.e. buffering acid deposition and sequestering metals to the sediment), it is associated with the abundant growth of 'nuisance algae'. Carbon is a primary nutrient required for the growth of algae and cyanobacteria. Carbon dioxide (CO_2) is the form of carbon most readily accumulated and utilized by algae and cyanobacteria for photosynthesis. However, cyanobacteria are also capable of assimilating HCO_3^- from their environment as a precursor to CO_2. At low pH and alkalinity the proportion of carbon as CO_2 is greater than that of HCO_3^- (e.g. pH 6, the proportion of CO_2 = 0.725 and HCO_3^- = 0.275). With increasing pH, the proportion of carbon as CO_2 decreases relative to HCO_3^- (e.g. pH 9, the proportion of CO_2 = 0.025 and HCO_3^- = 0.972). As a result, cyanobacteria have a competitive advantage over other algae in alkaline environments. Consequently, alkaline freshwater lakes frequently support abundant populations of cyanobacteria that develop severe surface accumulations or 'blooms' during the warm summer months.

Hardness: a measure of the amount of divalent cations in the water, primarily calcium [Ca^{+2}] and magnesium [Mg^{+2}]. The factors influencing hardness of surface waters are the same as those influencing alkalinity (i.e. the composition of the underlying bedrock, surficial deposits and soils within a watershed). Concerns with hardness relate mainly to excessive $CaCO_3$ build-up in water lines, though it can also influence the form and toxicity of numerous heavy metals.

Specific Conductance (or conductivity): refers to the ability of a solution to carry an electrical current and is a measure of the total concentration of dissolved charged particles (anions and cations) in water. It is an indicator of salinity, the relative concentration of salts in water, and can be used for estimating the total dissolved solids content of water, including inorganic salts (salts of carbonates, bicarbonates, chlorides, sulphates, phosphates, nitrates, etc. with calcium, magnesium, manganese, sodium, potassium etc.). The concentration of dissolved ions in lake water is largely influenced by the underlying soils and bedrock within a drainage basin. Geologic formations composed of igneous (e.g. granite and gneiss) and metamorphic (e.g. slate and schist) bedrocks are typically less saline than those derived from ancient sediments (e.g. sandstone, siltstone, shale, coal and limestone). Except for the granitic bedrock comprising the Canadian Shield, bedrock in Alberta is primarily sedimentary in origin. During past glacial and interglacial periods, erosion of this sedimentary rock resulted in the formation of deep surficial deposits (glacial tills) and soils across much of the province. Consequently, the underlying basins and surrounding watersheds of many of Alberta's lakes naturally contain high levels of dissolved solids in addition to metals and nutrients. Although small amounts of dissolved ions enter water bodies via surface runoff, groundwater inputs can be the predominant source for many of Alberta's natural lakes. As a result, the relative ionic composition of many lakes resembles that of their upper groundwater. For lakes receiving little groundwater input, precipitation and atmospheric fallout can be important sources of dissolved ions. The salinity of water is further influenced by climate, as the balance between precipitation and evaporation dilutes or concentrates dissolved substances. Dissolved salts elicit harmful effects primarily by altering an organism's osmotic pressure. For example, high ambient salt concentrations may decrease the osmotic pressure within aquatic vegetation, causing water to flow out of the plants to achieve equilibrium. As a result, the plants absorb less water, effectively stunting growth

and reproduction. Salinity influences the overall abundance and biomass of algae and cyanobacteria. The impacts of salinity on aquatic ecosystems can either be subtle (reduced diversity of aquatic life) or abrupt (reduced overall abundance of aquatic life). Currently, Alberta has no guideline for the protection of aquatic life with respect to salinity.

Major Ions: ions occur naturally in water as a result of geochemical weathering of rocks (and their derived soils), surface runoff and atmospheric deposition. The eight major ions - calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulphate, and chloride - account for most of the total dissolved solids in surface waters.

Fluoride: is present in trace amounts in soil and rocks and is released naturally to the aquatic environment by geochemical weathering. Fluoride is also released into surface waters from municipal wastewater as a result of fluoridation of drinking water.

Iron: is released naturally into the aquatic environment by weathering of sulphide-rich ores and rocks and from the leaching of sandstones. Human sources include the burning of coal, acid mine drainage, mineral processing, sewage and landfill leachates.

Aluminum: is abundant in rocks and clays, and can be mobilized from soils by natural weathering. Sources also include effluents from industries that use aluminum in their processing or use alum as a flocculent. Low concentrations are not a concern, but toxicity of aluminum increases if the pH of the water is less than 6.

Arsenic: is released naturally into the aquatic environment as a result of weathering of arsenic-containing rocks, from industrial and municipal discharges, and from combustion of fossil fuels. Arsenic is toxic to many life forms, though naturally occurring concentrations are usually low and pose no risk to aquatic life.

Barium: is a common element in the earth's crust, although only trace levels are normally found in natural surface waters.

Boron: is released naturally into the aquatic environment from weathering of rocks and soil and is present in municipal sewage.

Cadmium: is present in trace concentrations in fresh water as a result of natural weathering processes. Concentrations above about 0.01 mg/L can usually be attributed to human activities such as mining, agriculture and the burning of fossil fuels. Concentrations above this level may be toxic to aquatic life.

Chromium: is released naturally into rivers by weathering of rocks and soil. Industrial discharges, such as those from metal-plating facilities, are primary anthropogenic sources. Chromium is toxic to certain aquatic invertebrates at low concentrations, but fish are less sensitive.

Cobalt: is released into the environment from weathering of cobalt-rich ores and from anthropogenic sources such as emissions from coal burning industries.

Copper: sources to aquatic environments include the weathering of copper minerals and native copper and numerous human activities. Background concentrations in surface waters are usually below 0.02 mg/L., while higher levels are generally related to human activities.

Lead: is toxic to fish and other organisms, particularly in soft water. Although there are natural sources of lead, human sources often supply a greater quantity to surface waters. Sources include weathering of sulphides-rich ores, urban runoff, atmospheric deposition and industrial and municipal discharges.

Manganese: is an essential trace element for living things. Soils, sediments and rocks are significant natural sources of manganese, whereas industrial discharges are the primary source from human activities.

Mercury: occurs in all types of rock and derived soils and sediments. As a result, mercury exists naturally in surface waters. Human sources of mercury to the aquatic environment include industrial and municipal discharges, atmospheric deposition, industrial emissions and leaching from landfill sites. Mercury is of particular concern because of its toxicity to aquatic organisms and its adverse effects on human health.

Nickel: enters the aquatic environment through the weathering of rocks and as a result of human activities, primarily the burning of fossil fuels and from smelting and electroplating industries.

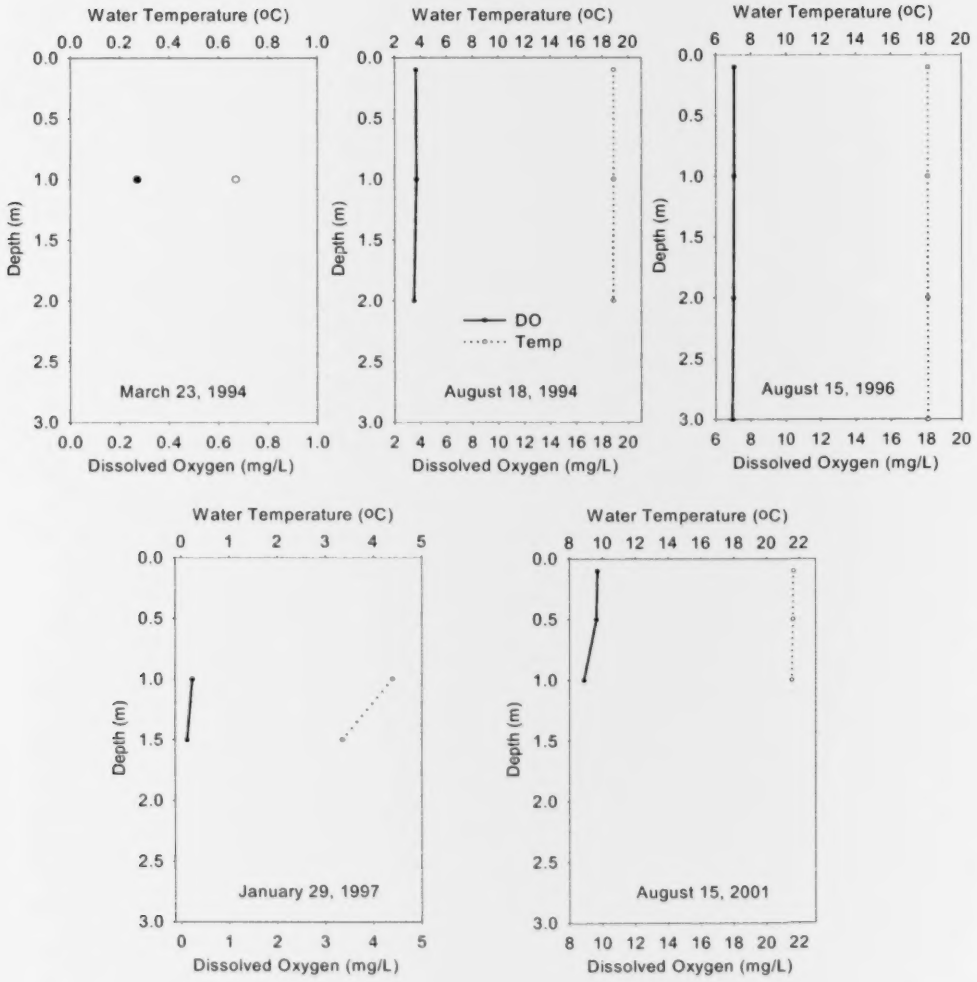
Selenium: enters surface waters as a result of weathering and erosion of soils and discharge from copper and lead refineries and municipal wastewater. Some geologic formations can release high amounts of selenium when exposed by surface mining activities.

Vanadium: is released to the aquatic environment primarily by surface erosion. The major human-related sources are from atmospheric deposition as a result of emissions associated with oil, gas and steel production.

Zinc: enters the aquatic environment primarily as a result of geochemical weathering and industrial and municipal discharges. Zinc is an essential element for living organisms, but can be toxic at high concentrations.

Appendix II

Lac Cardinal Depth Profile Data



Lac Cardinal Mean Annual Water Quality Data

YEAR	Number of Samples	Alkalinity (mg/L)	Bicarbonate (mg/L)	Calcium (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Chlorophyll-*a* (µg/L)	Fluoride (mg/L)	Hardness (mg/L)	Iron (mg/L)	Magnesium (mg/L)
1992	5	134	164	64.67		1.90	62.76	0.24	256	0.13	23.00
1993	7	122	145	54.33	14.00	2.03	156.30	0.24	230	0.18	23.00
1994	7	134	163	54.33		2.23	63.97	0.24	227	0.18	22.33
1995	5	130	154	67.33	7.00	2.53	78.26	0.26	277	0.19	26.67
1996	5	132	155	64.50	3.27	16.13	97.76	0.28	264		24.90
1997	4	130	156	56.97	1.48	2.03	39.18	0.27	214		17.47
2000	4	125	151	59.43	2.50	3.33	101.48	0.27	249		24.43
2001	3	78	90	36.90	2.50	4.00	120.95	0.30	178		20.90
2002	2	111	127	46.40	2.50	2.00	62.50	0.26	222		25.70

YEAR	Number of Samples	pH (units)	Total Phos-phorus (mg/L)	Potassium (mg/L)	Secchi Depth (m)	Silica (mg/L)	Sodium (mg/L)	Specific Cond-uctivity (µS/cm)	Sulfate (mg/L)	Total Dissolved Solids (mg/L)
1992	5	7.98	0.24	16.97	0.32	5.73	12.00	562	148.67	348
1993	7	8.46	0.32	16.73	0.33	2.13	12.00	519	135.67	317
1994	7	7.83	0.28	17.73	0.47	8.27	11.33	517	124.67	313
1995	5	8.09	0.25	19.07	0.50	9.90	13.00	596	167.33	375
1996	5	8.20	0.24	18.17	0.50	0.88	14.50	551	148.33	380
1997	4	8.11	0.24	14.17	0.37	0.29	9.10	453	96.93	276
2000	4	8.20	0.27	18.87	0.40	2.57	12.33	560	162.33	356
2001	3	8.50	0.35	19.00	0.38	0.60	12.00	472	153.00	293
2002	2	8.60	0.29	23.00	0.30	3.70	15.00	495	167.00	346